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THE EFFECT OF DRYING CONDITION ON POST FLOODING MECHANICAL PROPERTIES OF TIMBER SHEAR WALLS

Alistair Bradley¹, Wen-Shao Chang², Richard Harris³

ABSTRACT: Due to anthropogenic global warming, flooding is an ever more likely occurrence, with more intense periods of heavy rain leading to a very real and immediate increase in flood risk. Timber structures especially, due to their hygroscopic nature, face a unique risk of reduced load carrying capacity caused by flooding. To address the lack of research, a series of tests were conducted in order to categorise and understand the consequences of different drying methods on the behaviour of nailed sheathing-to-timber connections following a simulated flooding event. It has been shown that a range of drying process used following a simulated flood event, directly and negatively impact the structural performance of the tested specimens. Permanent reductions in strength, stiffness, energy dissipation capacity and damping potential were all observed. The degree to which these properties reduced was directly dependent on the drying method.

KEYWORDS: Timber, flooding, drying, shear wall, strength, stiffness, energy dissipation, damping ratio

1 INTRODUCTION

Due to anthropogenic global warming, flooding is an ever more likely occurrence, with more intense periods of heavy rain leading to a real and immediate increase in flood risk [1]. Timber shear wall structures (TSW) face distinct risk from flooding due to timbers hygroscopic nature and its use in conjunction with a wood based sheathing material such as plywood or OSB. Shear walls are at risk of reduced load carrying capacity from a number of sources, some of which include:

1. A weakening of the timber or sheathing. The relationship between strength and moisture content (MC) of timber is well documented [2].
2. A change in the microscopic structure of the timbers due to MC fluctuations may reduce load capacity. Liquid moisture may damage cells or cause dimensional changes that rupture fibres.
3. Micro-biological degradation. Moulds and rot pose both an environmental hazard to occupants and weakening risk to the wood products used.
4. Rusting of nails in joints. This can lead to either degradation in the nail strength or swelling induced stresses as a result of nail expansion through oxidation.

5. Induced stresses due to differential swelling of timbers and warping of members due to rapid moisture content changes.

Following a flood it is therefore vitally important to dry timber shear walls sufficiently in order to mitigate the risk of both structural damage and environmental hazard. A moisture content of 20% is normally recognised as the upper bound of what is acceptable for in service timber [2, 3]. 20% is taken as a practical threshold because:

- Most drying guidance suggests that a MC of 20% or lower, as measured by a two pin moisture meter at the surface, is sufficiently dry [4-7].
- Below 20% the timber is not at risk from micro-biological growth such as moulds and is generally below the FSP thus guidance assumes it to be of acceptable strength.
- Below the 20% limit it can be allowed to reach EMC with its environment without worry of further degradation.

There are many methods available for drying TSW structures following flooding, however there is little consensus as to which are most effective and least damaging. The most commonly cited methods of drying can be grouped into three categories: Natural ventilation, Dehumidification and Convection heating[6, 7]. All approaches to drying fit these categories, regardless of the methods used to control the drying environment. A number of documents [4-7] offer an excellent discussion

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of the various drying methods available to the victims of flooding and an exploration of how they work.

Despite an informative body of data on how each method works, there is little research into which are the most effective.

The main source of information in the UK, PAS64 [6], makes no mention of efficacy. Commercial drying of fresh felled timbers shows that the drying method used affects both the speed of drying and the quality and strength of the finished product [3]. It is thus realistic to assume that a similar state of affairs is true for drying after flood. This paper focuses on the effect different drying approaches have on the strength of in service timber after flooding.

It is reasonably assumed that all drying methods, given sufficient time, will eventually bring the MC below 20% and limit the biological risk to the timber however the effects of drying on the structure itself are underrepresented in current literature. Escaramaia et al. [8] studied a number of different wall constructions and investigated the leakage and subsequent drying rates. Only naturally ventilated drying was explored and no strength tests were conducted. Their work focused on absorption rate and performance of different constructions and renders in response to flooding. It did not assess drying methods for efficacy and, due to the variety of structural types investigated, has limited data with respect to timber. Leichti & Rosowsky [9] studied the effect of drying on full scale shear wall load capacity. This study tested walls after air drying only and concluded that the wetting/drying cycle had little effect on the walls lateral load resistance or energy absorption capacity, with only a loss of stiffness evident. The study did not however, investigate the effect of different drying methods on the capacity of the structure following flooding, focusing only on natural, unassisted drying.

Both studies mentioned assumed that the structure was sufficiently dry within 14 days and neither investigated the effect of alternative methods of drying. In real world flood recovery, generally an attempt will be made to speed the drying process via the use of mechanically assisted drying methods and the end point of the drying is determined by a moisture content target rather than a fixed time frame [6, 7]. Since both studies described investigated only natural drying, there is a limit to their real world applicability. Furthermore, it is not necessarily true that simply drying a timber structure is guaranteed to return it to its original load carrying capacity following flooding. It may well be that the removal of flood water by artificially aided means causes changes to the timber and sheathing that affect their ability to carry the design load. Despite the influence of flooding and the risk potential timber construction is exposed to there is a startling lack of research into this area.

2 Experimental programme

Since there is little comparative research into drying effects, a series of tests were designed conducted in order to categorise and understand the consequences of different drying methods on the behaviour of nailed sheathing-to-timber connections following a simulated flooding event.

Floods can be broadly categorised by depth into two types. For floods of more than 1m in depth the major risk is uplift or overturning of the structure [8]. Therefore only floods of less than 1m in depth need be considered when dealing with the issue of drying following flooding. It is not practical to perform repeated flood tests of full scale TSWs and then load test them, especially given the area of interest is the lower section actually exposed to flood water. Instead a series of connection details were produced. These connection details were fully immersed in fresh water for five days to simulate a flood event⁴. Control specimens were prepared and used as comparators for specimens exposed to varying degrees and methods of drying. This is explored further in Section 2.2. This test focused on OSB as a sheathing material due to its prominence within contemporary construction. Similarly these tests explore single shear connections as it is common to strip away the internal layer of wet sheathing on a wall, leaving only the cavity layer in place, see [7] for more information.

2.1 Specimen preparation

Connection specimens were prepared from quarter sawn Douglas Fir timbers, cross Section 140*38mm, and 9mm OSB/3 sheathing.

Based on guidance from [10], specimens were constructed with OSB panels 300*210mm and timber sections 210mm in length. Samples were fastened with hand driven, galvanized steel wire nails; 75mm shank, Ø3.75mm. Because the timber was quarter sawn, two nominal grain orientations were investigated. The orientation of the force applied was either parallel to the direction of the grain or tangential to the direction of the grain and the two orientations are referred to as parallel (PAR) and radial (RAD) respectively, see Figure 1.

2.2 Test environments

As discussed in Section 1, there are three broad categories of drying. Due to time constraints it was decided to ignore natural drying as this is known to be the slowest method of drying as well as the most studied. Instead, five "conditions" were defined within the capabilities of the equipment available that varied the temperature and relative humidity (RH) the specimens were exposed to. These conditions are as follows:

⁴ Although "normal" flood water and fresh water differ, the former carries a risk of biological hazard that is not warranted in experimentation.

1. **Control:** Un-Wetted samples to be used as comparators for other test data. Analogous to other specimens dry state behaviour prior to wetting and drying.
2. **Wetted:** Samples wetted for five days then load tested without drying.
3. **High humidity:** Samples dried in a controlled environment of 20°C and 60%RH before being load tested.
4. **High temperature:** Samples dried at 105°C and 0%RH before being load tested.
5. **Low humidity:** Samples dried in a controlled environment of 25°C and 30%RH before being load tested.

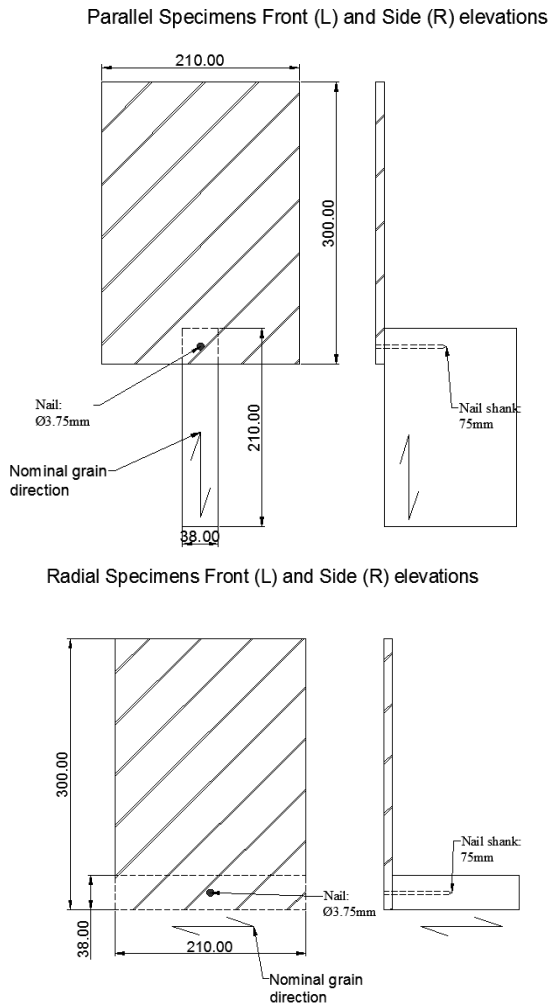


Figure 1: Diagrams of parallel (Top) and radial (Bottom) specimens showing front elevation (L) and side elevations (R). All dimensions are in mm.

These conditions (hereafter referred to by condition number) allow the effect of variations in temperature and RH to be assessed. For each condition, three specimens of each orientation were tested. The end point for the drying process was defined as a moisture content of 20% or less.

Whilst it would be interesting to record and compare the time taken to reach a dry state it was not possible to continually monitor the MC of each specimen with respect to time. A rough estimate of time to dry can be given however it is not a precise measure. The experimental process did not include a means to “halt” the drying process at exactly 20% MC and hold the specimens at that particular EMC. Due to the number of samples required it was decided to perform load tests when the target MC had been achieved or as soon as possible afterwards. If it was not possible to test specimens immediately they were stored in the appropriate drying environment until such time as they could be tested. As such, some specimens dried beyond the 20% level whilst waiting to be load tested. The MC of the samples (OSB and timber) was recorded before wetting, immediately after five days of wetting and before testing. These data are presented in Section 3.1. MC values were taken as surface readings using a two pin, capacitance type, moisture meter capable of reading from 6% to 44%.

2.3 Mechanical testing

Specimens were subject to cyclic loading using an 100kN Dartec Testing Frame with an Instron 8800 Control Tower running “Fastrack” acquisition software recording at 1Hz. Displacement (δ mm) and Force (F kN) values were recorded using the test frame on board sensors. A check between an external transducer and machine values was made, with δ and F values agreeing fully ($R^2=0.999$). Cyclic loading, based on CUREE simplified loading protocol [11], is in detailed Table 1 and was cycled at 0.07Hz.

Table 1: Parameters of the loading regime for the cyclic tests based on the CUREE simplified loading protocol. Load step 8 is equivalent to Δ where $\Delta=7.439$ mm. The load is cycled at 0.07Hz. See [11] for further information.

Load step	Fraction of Δ	Number of cycles	δ (mm) per cycle
1	0.05	6	0.372
2	0.075	7	0.588
3	0.1	7	0.744
4	0.2	4	1.488
5	0.3	4	2.323
6	0.4	3	2.976
7	0.7	3	5.207
8	1.0	3	7.439
9	2.0	3	14.878

Strength parameters were determined from the hysteretic envelope by plotting a curve through the loop peaks. A visual inspection of each specimen was made before, during and after loading and relevant images recorded. This visual inspection in combination with the loading data allows both qualitative and quantitative analysis to be made.

The tests were conducted as displacement controlled tests, recording the machine applied δ and the resulting F acting on the specimen. The timber was held fixed thus the measured δ is the equivalent movement of the OSB and nail section of the tested connection.

3 Results & discussions

Test results and calculations performed are presented here along with relevant discussion.

3.1 Drying of specimens

As discussed in Section 2.2, measurements of moisture content of the samples were made before and after wetting as well as after drying. This allows a coarse comparison of the drying efficacy to be made although only an approximate time comparison can be made.

Prior to soaking the samples had average moisture content values of $MC_{OSB}=9.8\%$ (1.1%) and $MC_{Timber}=14.5\%$ (2.7%) where parenthetical values are standard deviations. It can be seen that the values are consistent between samples with little variation. Soaking for five days caused these values to increase to $MC_{OSB}=44\%$ (0%) and $MC_{Timber}=32\%$ (3.01%). The OSB readings were all beyond the scale for which the moisture meter could read and clearly well above the FSP. The timber values were all also over the FSP with the maximum $MC = 36\%$. Again, little variation is present in terms of soaked MC values. After drying, the sample MC's were re-measured prior to load testing. The averaged values were $MC_{OSB}=9.9\%$ (7.0%) and $MC_{Timber}=10.6\%$ (6.7%). It can be seen that there is far more variance as a result of the different drying methods. It is therefore more useful to view the data for each drying condition individually instead of as a group average. Table 3 shows these data as well as approximate time taken to dry.

It is clear that there are significant differences between the drying methods used and the length of time taken to dry to the target MC. Condition 4 took no more than three days to achieve a dry state whereas condition 3 and 5 took two weeks and a week respectively. Condition 4 was so effective it dried the specimens to the point that the MC meter could not obtain a reading (0% MC); most likely removing all moisture from the specimen.

Conditions 3 and 5 both remove moisture from the timbers but at a far slower rate than condition 4. Condition 5 takes roughly half the time of condition 3 to achieve the same level of drying (~16% MC in both OSB and timber). This basic data would suggest that condition 4 is the most effective drying solution in terms of moisture removed and (rough) time to dry, however, the MC data does not capture any of the changes in the connections and load carrying capacity. It is also clear that it is impractical in a domestic or commercial structure to achieve a temperature of $105^{\circ}C$; the energy input is costly, especially if scaled to

the size of even a nominally “average” dwelling. Additionally the environment created is impossible to inhabit⁵. Condition 4 of course shows that providing energy input via temperature increase is an effective method of simply removing moisture from the specimen and illustrates the subsequent structural impact. Furthermore it can be seen by comparison of condition 3 and 5 that decreasing the RH is also an effective method of improving drying time.

From these data alone it would be reasonable to conclude that the most efficacious drying method is condition 4 however, as discussed previously, it is impractical and ignores limitations in terms of cost and comfort. The MC and time data also captures none of the potential structural changes and damage in the specimens as a result of their exposure to different drying environments.

From the data it is possible to state that the most efficacious drying method for timber is one that balances an increase in temperature with a decrease in RH within reasonable cost and environmental limits. That is, not too hot or too dry, so as to limit both the cost and discomfort to occupants. It is interesting to note that the orientation of the specimen has no significant effect on its speed of drying.

3.2 Strength of specimens

As described in Section 2.3, specimen strength is taken as the peak of the load displacement curve, where the load displacement curve was recovered from the hysteretic loop envelope by plotting a curve through the loop peaks. There is an apparent reduction in strength immediately visible (See Figure 2). In the parallel specimens the averaged peak strength of the control specimens was 1.65kN. The specimens exposed to conditions 2 and 3 exhibit a reduction in strength of approximately 40%. Condition 4 recovers 69% of the control specimen strength and condition 5 recovers 73%. There is a similar trend in the radial specimens although the peak control strength is 1.73kN which is marginally greater than the radial. Whilst the decrease in strength is again apparent the condition 2 specimens show the greatest recovery to original strength (~78%).

It is clear that the process of wetting and subsequent drying has an effect on the specimen strength, leading to a non-recoverable decrease in overall strength, regardless of the specimen orientation. It must however be remembered that this strength reduction relates only to the connection detail and may not necessarily be valid for a full scale wall. The most effective method of drying is therefore one that allows for the greatest recovery of strength parameters

⁵ There are systems that use hot air to achieve these sorts of temperatures in a highly targeted fashion however there is some debate as to whether they are appropriate for use with timber and they are not investigated here.

whilst maintain a balance of reasonable time to dry, appropriate heat input and low RH.

#

3.3 Visual observations

Visual inspection of the specimens revealed some interesting trends. All specimens upon completion of the wetting stage showed signs of thickness swelling in the OSB. In some cases this has resulted in a “dishing” of the

OSB around the nail head and in others it has resulted in the nail head punching through the OSB layer.

The dishing is a result of insufficient swelling force in the OSB to shear the fibres at the nail head. The punching is caused by sufficient force to cause shearing of the fibres. It is likely that the swelling forces involved are similar and the cause of the two alternative behaviours is differences between local fibre make up, density and orientation in the OSB in the vicinity of the nail head.

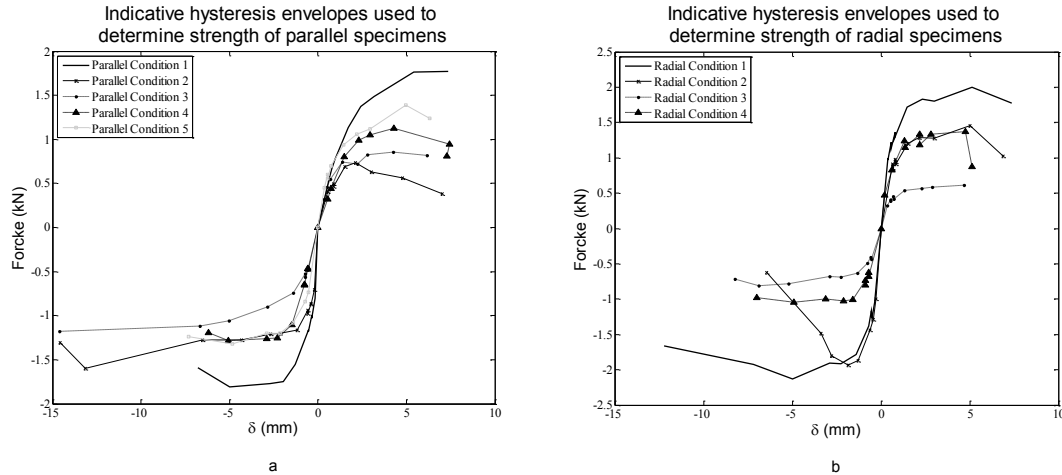


Figure 2: Indicative, individual hysteresis envelopes for each condition. A decrease in strength with respect to condition 1 is visible for all other conditions, indicating the wetting and drying process has affected the strength of the connection details. Parallel specimens are plot (a), radial are plot (b).

Upon drying clear differences between specimens become evident. Specimens subject to Condition 4 showed significant shrinkage, to the point that the OSB became fully free to rotate about the nail shank. The OSB itself lost much of its structural integrity and individual fibres could be peeled from the board readily. The fibres were extremely brittle and easily crushed by hand. Gaps were also visible between layers of the OSB where swelling and shrinkage had split open laminate layers. The timber itself showed no significant visual damage and the nail was still firmly embedded

Condition 3 and 5 were similar to each other. They did not show the same level of degradation that the specimens subject to condition 4 did. The thickness swelling from the wetting was still present and the OSB remained rotationally restrained by the nail. This thickness swelling and the resulting deformation of the OSB shows there is no pull out of the nail from the timber, the swelling forces are too small cause the nail to pull out. Two timbers showed signs of minor insignificant splitting. The most interesting aspect to note was only visible after load testing and disassembly of the specimen for analysis. Following disassembly it was noted that there appeared to be a dark, wetter patch underneath the OSB in some of the condition 3 samples indicating that the specimen was still not fully

dry. When tested it was discovered that the MC in these dark patches was above the 20% threshold required. This highlights an important issue; having utilised a fairly standard method for measuring MC that indicated that the specimens were sufficiently dry, further inspection revealed they were not. There were areas of trapped moisture in parts of the specimen that were inaccessible without disassembly. Certainly in a full size wall these areas would never have been noticed, hidden as they are between the OSB and timber. It is arguable that the method of taking surface or near surface moisture readings is therefore inadequate if such locations of elevated MC can be missed. Even using longer pins with the moisture meter, it is unlikely these wet spots would have been correctly diagnosed in this test. This is therefore a danger that a timber structure may in fact not be fully dry despite MC readings indicating otherwise. This may have impacted on the mechanical properties of these specimens and would certainly put a real structure at risk of mould growth or rot developing due to insufficient drying. In determining an optimum drying regime it is sensible to account for the fact that some approaches are more prone to this risk.

3.4 Failure mode of mechanical tests

Examination of the specimens following load testing showed great consistency in failure mode of the shear

connection. As defined by Eurocode 5 [12], the specimens failed in either mode **a** or **d** (Figure 3). These two modes do not accurately reflect the reality of the specimen failure. In reality the failure mode was more similar to a combination of the two modes. This combined mode (mode **y**) is the right-most diagram in Figure 3. It can be seen that the timber crushing is exceptionally limited, the nail bending is limited to the OSB timber junction and the OSB experiences severe deformations. This failure mode assessment is based on the examination of the tested samples (See Figure 4 & Figure 5). The OSB panel tended to rip through the free end of the board, as shown in Figure 5. The crushing of the timber (Figure 4) is not apparent until the specimens are subject to excessively large deflections. The OSB crushing however occurs as soon as even small deflections are applied. This was true for all tests, including the condition 2 specimens, indicating that the softening of the timber due to MC increase is less significant than the equivalent softening of the OSB. From this data it can be concluded that the OSB is the failure point in each connection, with the slight timber crushing insignificant in comparison. This is true of both control specimens and those subject to different environments. The OSB is the critical link in the system, with the timber being extremely unlikely to be a source of failure.

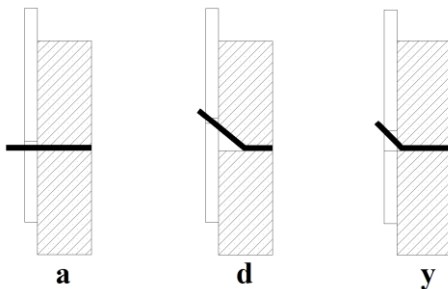


Figure 3: Failure modes observed in load tested specimens. Modes **a** and **d**, as given by Eurocode 5, do not accurately reflect the actual failure of the connections. Based on inspection of failed specimens, mode **y** is proposed. Figure based on [12], Section 8.2.

The sheathing shown in Figure 5 exhibited an extremely clean tearing. Although all panels failed in this fashion, higher moisture contents resulted in either greater material loss at the panel free end or a less clean tear through the sheet.

3.5 Stiffness degradation

It is expected that the stiffness, k , of the connection should reduce as cyclic loading progresses as a result of degradation from hysteretic energy dissipation. That is the observed outcome of these tests, with stiffness exhibiting a negative logarithmic decrease with respect to total displacement. Different drying conditions resulted in

different initial values of stiffness, ranging between 33% and 96% of the pre flood initial stiffness.

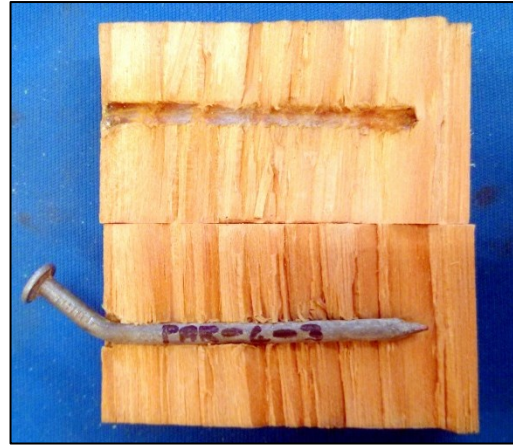


Figure 4: Specimen PAR-4-3 cross section following load testing. Note the minimal crushing of the timber at the bend in the nail shank. This behaviour is similar for all test specimens. The degree to which the timber crushed varies little.



Figure 5: Failure of OSB board from specimen PAR-4-3. Note the linear "rip" in the sheathing board. The free end of the board shows evidence of material being pulled out of the OSB.

Inspection of Figure 7 shows that the radial specimens all exhibit greater initial stiffness than the parallel specimens, although by the conclusion of the tests the residual stiffness's of both orientations were all a similar value of approximately $k=0.1\text{kN/mm}$ or less. The radial specimens therefore lose stiffness at a greater rate than the parallel specimens. Condition 1 specimens consistently have a higher stiffness than all other conditions regardless of the degree of displacement. For both test orientations, at $\delta=20\text{-}30\%$ the differences between conditions are insignificant. The values for k are all but converged and beyond $\delta=50\%$ there is little residual stiffness in any specimen. It is worth noting that $\delta=20\text{-}30\%$ is equivalent to $17.6\text{mm} < \delta < 26\text{mm}$. Beyond these values the deflections can be considered excessively large for a serviceability limit. The most significant reduction in stiffness is present in the specimens exposed to condition 4. After drying they have

recovered just 30-50% of the initial stiffness and rapidly decline to negligible stiffness. For the parallel specimens, conditions 3 and 5 are very closely grouped and have recovered the greatest percentage of initial stiffness. Conditions 3 and 4 are comparable between the radial and parallel tests. It is interesting that the specimens with the greatest residual percentage of initial dry stiffness are those subject to condition 2, wetted for five days. In both orientations they are initially >90% of the dry stiffness and in the case of the radial specimens especially, very closely match the decrease seen in the control specimens. This residual stiffness could possibly be accounted for by a number of factors. If the drying process in some way alters or damages the timber and OSB fibres then the wetted, undried specimens would not have experienced this damage yet, hence the high residual stiffness. This explanation however, does not take into account the softening of the fibres due to wetting. It may be that the OSB swelling releases more free length of fibre from the laminate matrix to slide and, despite now being softer, the wetter fibres have more effective length to resist the applied load, compensating for the moisture induced softening. There is also the possibility that the trapped moisture is itself somehow providing stiffness but this is unlikely.

Of the drying conditions investigated, it was condition 5 in the parallel specimen tests that showed the greatest percentage recovery to initial stiffness (72%) although this is only marginally greater than condition 3 (69%). The radial specimens do not reflect these results, with condition 3 specimens recovering only 50% of their original capacity. It appears that there is an irretrievable loss of stiffness caused by the drying process of at least 30%. This is comparable to the results reported by Leichi & Rosowsky for full scale walls [9].

3.6 Energy dissipation

Specimens were mechanically tested under cyclic loading in order to determine how much dissipation capacity was recovered in comparison to the original state following the simulated flood and drying. The assumption is made that the control specimens represent the pre flood, "original", capacity of the connections. Values of total energy dissipation and cumulative energy dissipation were calculated from the collected test data for each specimen in order to provide a full comparison between drying conditions. Table 2 shows the total, average energy dissipation for each drying condition for both radial and parallel specimens. The radial control specimens dissipated ~20% more energy than those control specimens oriented parallel to grain. Conversely, the radial specimens subject to condition 4 dissipated 30% less energy than the parallel specimens.

The energy dissipated by control specimens is approximately 100 Joules. All specimens subjected to

alternate conditions dissipated less total energy. The percentage of control energy dissipated by each specimen is given in Table 2. It is evident that drying via condition 5 results in the closest percentage return to original energy dissipation capacity (94.6%) and that condition 3 in the parallel orientation, and condition 4 in the radial, result in the lowest percentage of original dissipation capacity.

Table 2: Energy dissipation as a percentage of control specimen energy dissipation for each test condition. Values are similar in both orientations apart from condition 4 which shows a variation of some 20%.

Condition	Percentage of control energy dissipation (average)
Parallel	
1	100 ()
2	75.7 ()
3	67.2 ()
4	78.0 ()
5	94.6 ()
Radial	
1	100 ()
2	62.15 ()
3	53.54 ()
4	42.84 ()

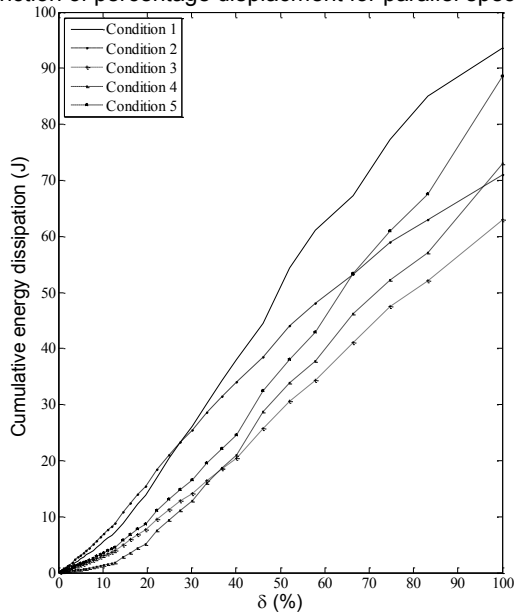
Table 2 is important as it demonstrates that the drying method employed does affect the structural performance of the timber connection detail. The specimens subjected to condition 3 and 4 recovered roughly 20-30% less energy dissipation capacity than those exposed to condition 5. Condition 5 has had the least impact on the energy dissipation capacity of the specimens.

Figure 6 shows the cumulative energy dissipation for parallel (a) and radial (a) specimens as a function of the percentage of total displacement. The specimen behaviour is as expected; a linear increase in energy dissipation is seen as the percentage of total displacement increases. The dissipation of energy for different drying conditions is linear, with different conditions dissipating energy at different rates. It can therefore be concluded that all are dissipating energy through the same mechanism. Due to the simplicity of the system, a single shear connection, there is only one realistic method of energy dissipation. Were the mechanism of dissipation to change the shape of the graph would be expected to change, that is, no longer linear. Since the rate of dissipation changes but the mechanism remains constant, the change in total dissipation capacity must be a result of a change to the timber or OSB structure due directly to the drying process the specimen is subjected to. This change in the material causes the reduction in energy dissipation capacity with respect to original capacity. This again shows that the drying history of the structure impacts its post flood performance.

Table 3: Moisture content data for individual test conditions for each orientation. Conditions 1 and 2 are not subject to drying, as discussed previously in Section 2.2, thus only initial (*i*) and wetted (*w*) values are given as appropriate. The figure for time to dry is indicative; it is not a precise value.

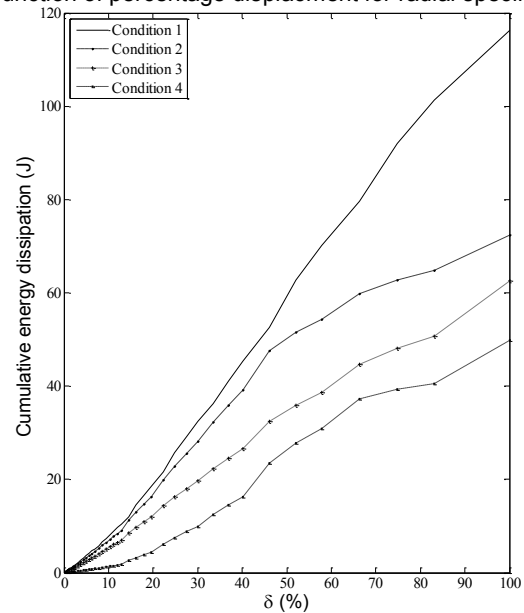
Orientation	Condition	MC _{OSB} (%)	MC _{Timber} (%)	Approximate drying time
PAR	1	10.7 (0.4) <i>i</i>	14.3 (3.6) <i>i</i>	N/A
	2	44.0 (0.0) <i>w</i>	32.0 (8.7) <i>w</i>	N/A
	3	16.6 (0.9)	16.3 (0.5)	14 Days
	4	00.0 (0.0)	00.0 (0.0)	2-3 Days
	5	16.0 (0.8)	14.3 (0.5)	7 Days
RAD	1	9.0 (2.2) <i>i</i>	14.0 (0.0) <i>i</i>	N/A
	2	44.0 (0.0) <i>w</i>	33.7 (2.6) <i>w</i>	N/A
	3	14.0 (1.4)	15.0 (0.0)	14 Days
	4	0.00 (0.0)	00.0 (0.0)	2-3 Days

Cumulative energy dissipation as a function of percentage displacement for parallel specimens



a

Cumulative energy dissipation as a function of percentage displacement for radial specimens



b

Figure 6: Cumulative energy dissipation as a function of total percentage displacement for parallel (a) and radial (b) specimens for all test conditions (averaged). All conditions exhibit an approximately linear relationship between displacement and energy dissipation, indicating the same mechanism responsible.

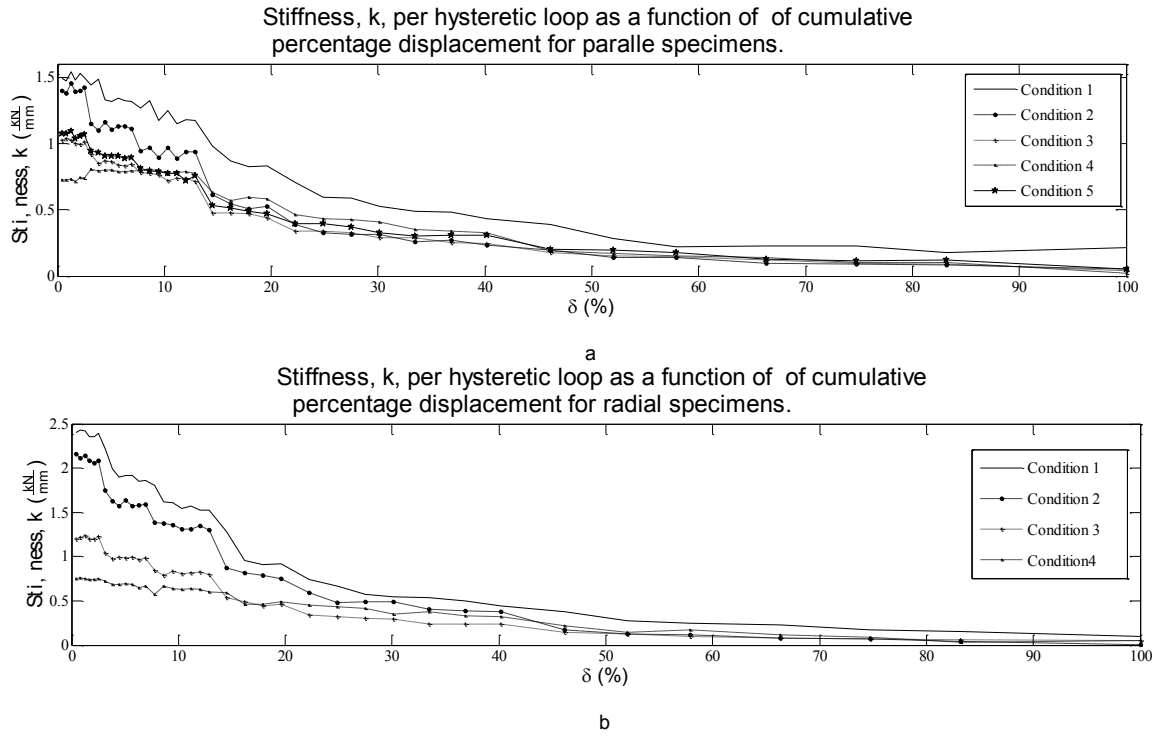


Figure 7: Stiffness of specimens as a function of displacement where stiffness, k , is taken as the secant stiffness between individual hysteretic loop peaks and troughs. Parallel specimens are the upper most plot (a), radial specimens the lower (b).'

3.7 Equivalent viscous damping ratio

The equivalent viscous damping ratio, ζ , is given by:

$$\zeta = \frac{A_h}{4\pi A_E}$$

where A_h is the energy dissipated within the hysteretic loop and A_E is the equivalent elastic energy dissipation between loop ends. This value gives an indication of how quickly a system is damping energy. Values of ζ were calculated for each group of specimens for each orientation. The values of ζ are plotted in Figure 8. They are plotted against Ω ; displacement expressed as a fraction of the connection fastener diameter in order to convey the scale of displacements with regard to the specimen geometry. Beyond $\Omega = 3$ the displacements are excessively large and the specimen is beyond any reasonable SLS. It is apparent that the specimens exposed to condition 2 both have greater damping ratios than the control specimens. It is also clear that those specimens exposed to condition 4 suffer the greatest loss of damping with respect to the control. The value for ζ for condition 4 for both specimen orientations is consistently less than half of that of the control ($<4\%$ compared to $\sim 8\%$). In the parallel specimens it can be seen that condition 3 and 5 are closely matched and, crucially, the value of ζ is less than that for the control specimens. Similarly, in the radial specimens, condition 3, although closer to the ζ values of condition 1 than the parallel specimens, is still reduced in value.

Regardless of the drying method there has been an irrecoverable loss of damping in all specimens dried. Similar to other mechanical properties, the type of drying affects how much loss in capacity occurs with condition 4 resulting in the greatest reduction in ζ .

It is important to remember that due to the regular increases in δ the ζ values are not able to properly settle. Furthermore, these damping values are for a single shear connection, not the entire structure.

4 Limitations

There are a number of limitations that must be accepted when drawing conclusions from these test data. Firstly, the use of connection detail specimens results in a smaller volume of timber subject to drying. It may be that due to their smaller size the test pieces dried faster than a real wall would have. Similarly, the specimens were dried in a totally controlled environment whereas real structures tend to be exposed to single sided drying. This again may have led to an increase in the rate of moisture removal from the specimens. Finally, the number of specimens tested is low and, if increased would allow greater certainty of the results.

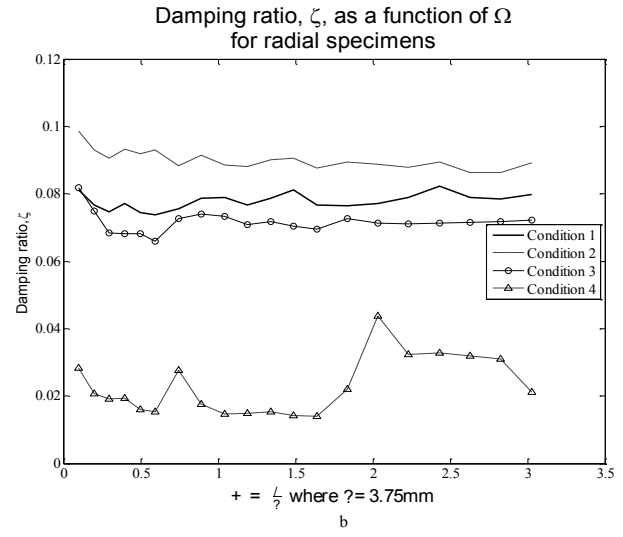
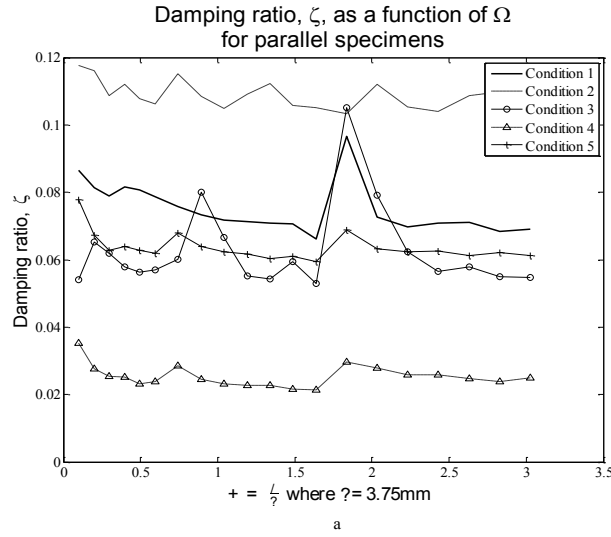


Figure 8: Damping ratio, ζ , plotted as a function of Ω for parallel (a) and radial (b) specimens. There is a clear loss of damping in all dried specimens and the method of drying affects the degree to which damping ability is reduced.

5 Conclusions

It has been shown that the drying processes utilised following a simulated flood event directly and negatively impacts the structural performance of the tested specimens. It has also been shown that the extent to which the drying negatively impact on the mechanical properties is dependent on which drying condition is used.

As discussed in Section 3, there are various factors that influence the behaviour of the specimens during testing. It has been shown that all dried specimens suffered a reduction in connection strength and a loss in connection stiffness. It has also been shown that the energy dissipation potential for the dried specimens is consistently less than those in the un-soaked, original condition. The energy dissipation of a specimen is directly correlated to its drying history, with those samples subjected to condition 5 recovering the greatest percentage of their original energy dissipation potential. The stiffness degradation of specimens is similar and is in broad agreement with previously published results. The uniformity with which stiffness degradation occurs suggests that it is a factor common to all drying conditions. The losses in specimen strength follow this same pattern.

The results obtained by these experiments indicate that each of the methods used to dry specimens adversely affects its load carrying capacity. The rough drying times (Section 3.1) show that exceptionally high temperature drying is the fastest method of moisture removal however, the results of the mechanical testing show that this results in greatest percentage loss of mechanical properties in comparison to the dry state. Conversely, we can see that the specimens exposed to a medium heat and low RH environment (condition 5) have not only dried within a reasonable time (7 days) but have also recovered the greatest percentage of their original mechanical capacity.

The similarity in failure mode, loss of stiffness, as well as the linear behaviour shown in terms of energy dissipation (Figure 6) indicate that regardless of the drying conditions, specimens are dissipating loading energy by the same mechanism. This shows that the loss of structural capacity must be a result of a material change due to drying method

Whilst some of the differences in specimen behaviour could be accounted for by slight differences in MC, the major variable is the drying condition employed. The reductions in stiffness and loss of energy dissipation potential are all attributable to the drying process applied and are likely due to the fact that some drying conditions cause damage to the micro-structure of the timber and OSB, hence the decline in structural performance. It is therefore suggested that the optimal drying strategy is one that results in a balance between speed of drying and maximum, pre-flood state, load capacity recovery. In this group of tests it was condition 5 that best fitted these criteria with a mix of gentle heating and low humidity resulting in a seven day drying period and greatest recovery of pre flood load capacity.

In practical terms these results indicate that the choice of drying method used on for full size shear walls following a flood event is important. It is clearly not sufficient to simply dry to a target MC, rather care must be taken to select a drying method that ensures the maximum recovery of pre-flood mechanical properties.

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